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(54) Ink-jet print head with integrated driving components

(57) In an ink jet printhead (100) comprising ejection resistors (Ri) and MOS transistors (TRi) for supplying the resistors the energy for ejecting droplets of ink, integrated on the same semiconductor substrate, a given range of values is defined for the ratio of the channel resistance (Rc) during conduction of the MOS transistor to the resistance (R) of the ejection resistor so that the energetic operating point (EI) of the ejection resistor is automatically compensated for variations in temperature (Ts) of the substrate, thereby assuring quality of printing and preventing ejection resistor conditions of operation liable to damage the resistor itself.

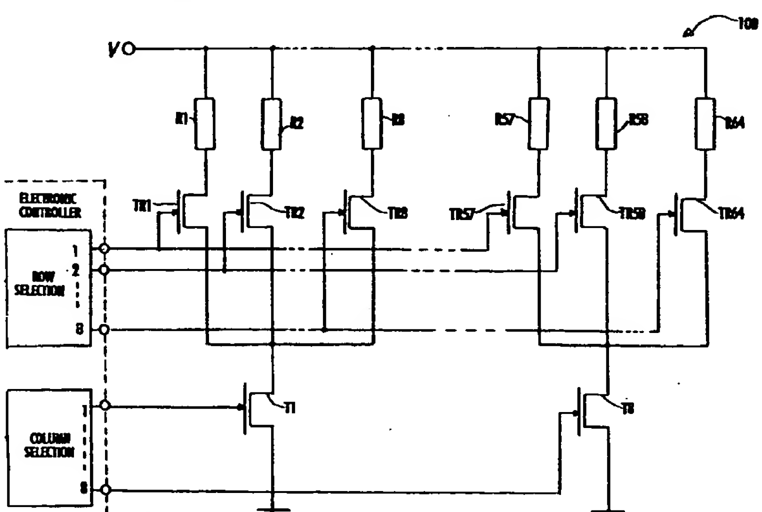

FIG. 1

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Descripti n

TEXT OF THE SPECIFICATION

Technical field of the Invention - The present invention relates to a printhead used in equipment for forming black and colour images on a printing medium, generally though not exclusively a sheet of paper, with the thermal ink jet technology and, more particularly to a printhead with integrated driving components.

Related Technological Art - Equipments of the type described above are known in the art, such as for example printers, photocopiers, facsimile machines, etc., and especially printers used to print documents using printing means generally consisting of fixed or interchangeable printheads.

Composition and general mode of operation of an ink jet printer, as also of the associated ink jet printhead, are already well known in today's art, so that a detailed description shall not be provided herein but only a more detailed account of some characteristics of the heads of relevance to the understanding of this invention.

A typical ink jet printer schematically comprises:

- a system, selectively actuated by a motor, for feeding the sheet of paper on which the image is to be printed in such a way that the feeding occurs in a given direction in discrete steps (line feed),
- a movable carriage, running on ways in a direction perpendicular to the sheet feeding direction and selectively actuated by a motor so as to perform forward motion and return motion along the entire width of the sheet,
- printing means, generally, for example, a printhead removably attached to the carriage and comprising a plurality of ejection resistors, deposited on a substrate (usually a silicon wafer) and arranged inside cells filled with ink, each one connected to a corresponding plurality of nozzles through which the head is capable of ejecting droplets of ink contained in a reservoir,
- an electronic controller which, on the basis of information received from a "computer" to which it is connected and of presettings established by the user, selectively commands both the above motors and also the printhead, causing ejection from the latter of droplets of ink against the surface of the sheet, thereby forming a visible image.

According to a recent evolution of the known technology, in addition to the ejection resistors, the printheads also comprise integrated resistor drive components on the same semiconductor substrate. Fig. 1 shows a wiring diagram of a printhead 100, comprising as well as the ejection resistors Ri (i=1,..64) and the relative connections, gen rally produced using thin-film t chnology, electronic components TRi (I=1,..64) for driving of the resistors. Typically these electronic components are integrated MOS transistors, i.e. produced by th known semiconductor integrated-circuit technology techniques on the same silicon substrate, and selectively supply the energy for heating of the resistors. All the ejection resistors Ri are in turn connected to a voltage V power supply. From the electrical viewpoint, thes integrated driving components TRi, all with essentially the same geometrical and electrical characteristics, and the relative ejection resistors Ri associated with them, are laid out in a matrix of rows and columns, according to methods of operation known in the art, in order to reduce the number of connections and contacts between them and electronic controller 101 to a minimum.

The electronic controller 101 comprises row and column selection circuits for selectively sending commands to transistors TRi and Ti respectively.

Fig. 1 illustrates, as a non-exhaustive example, the electric circuit of a printhead with 64 nozzles, containing 64 ejection resistors Ri laid out in a matrix of 8 rows by 8 columns, corresponding to which there are 64 MOS drive transistors TRi divided into 8 groups; each of these groups is in turn connected to earth through a MOS transistor Ti, which may have different geometrical and electrical characteristics from those of transistors TRi.

Naturally the number of ejection resistors and their division into rows and columns may be amply varied in function of specific printhead characteristics.

Method of operation of head 100, the electric diagram of which is illustrated in Fig. 1, is as follows:

when the electronic controller 101 simultaneously activates, for example, the "rows 2 selection" command and the " columns 1 selection" command, transistors TR2 and T1 start to conduct. With these two transistors simultaneously conducting to earth, the current supplied by the voltage V power supply is enabled to flow through resistor R2; this current is converted into thermal energy by Joule effect in ejection resistor R2, causing the latter to heat very rapidly to a temperature in the region of 300 °C.

A first portion of this thermal energy is transferred to the surrounding ink in contact with resistor R2, vaporising it and thus causing the ejection of a drop of given volume through the nozzle connected to the cell housing resistor R2; a second portion of the thermal energy is lost by conduction through the common substrate (the silicon wafer) on which the ejection resistors are deposited, increasing the temperature Ts of the substrate, of the head as a whole and of the ink it contains, with respect to the ambient temperature.

Incidentally, it must be noted that this rise in temperature may be confined to the surrounding region of some of the ejection resistors of the head only, due to the fact that the current printing job may require preferential activation of some nozzles only, and the diffusion of heat by conduction in the substrate is not sufficiently rapid to obtain a uniform distribution of temperature.

The ph nomenon of ejection of an ink droplet may be better understood when examined with reference to

the graph in Fig. 2, illustrating th pattern, measured experimentally and represented by curve 3, of volume VOL of the ink droplet ejected by a nozzle in function of the thermal energy Ė supplied to resistor Ri disposed in the cell connected to the nozzle, for a given, constant value of substrate temperature Ts.

As shown by the graph, under a value Es (threshold energy) the drop is not formed, since resistor Ri does not reach a temperature high enough to vaporise the surrounding ink. By increasing the energy E supplied to the resistor from value Es to value Eg (knee energy), volume VOL of the droplets ejected increases in a way substantially proportional to the increase in energy E supplied to resistor Ri. Conversely, above the Eg value, volume VOL remains substantially unchanged for increases of the energy E supplied to resistor Ri.

This asymptotic characteristic of the pattern of droplet volume VOL is extremely useful and is taken into consideration when defining the typical working value El for the energy E to be supplied to resistor Ri (energetic operating point). In actual fact, having a constant drop volume means that diameter of the dot on the paper will be constant, as too will density and uniformity of the images, whether black or colour. In other words, printing quality will be constant, a very important feature which is greatly appreciated by the users of printers.

Thus current practices adopt a compromise value for El, which is slightly greater than Eg. This guarantees, in the first place, that limited fluctuations of the thermal energy E supplied to resistor Ri due to various factors, such as drifts induced from production processes, or variations of the real operating conditions, do not entail significant variations of the volume VOL of ejected droplets. This is because of the fact that the energetic operating point of the ejection resistors is in any case inside the asymptotic portion of curve 3 and thus creation is avoided of the unstable operating conditions that could arise if El were to drop below Eg and droplet volume were to become variable, following the fluctuations of Eg.

Secondly, it ensures that the fraction of energy supplied to resistor Ri in excess of the minimum amount needed to obtain ejection of a droplet of constant volume does not result in a general increase in temperature of the substrate above the acceptable maximum value, liable to cause damage that would compromise proper operation of the printhead, or in a local increase in temperature above the optimum value of operation of even one ejection resistor. This would produce a phenomenon of deposition of carbon residues, resulting from decomposition of the ink on the resistor. Consequently, useful printhead life would be reduced, possibly even considerably, and failures of operation of the printhead would result due to failure of the nozzle concerned to eject ink.

However, as a fraction of th energy supplied to resistor Ri always results in heating of the substrat , consideration must be given to the phenomena caused by variation of temperature. Firstly, there is a variation of the threshold energy value Es because, as the temperature increases, the Es value needed to institute ejection of a droplet decreases: this is due to the fact that, as its starting temperature is higher, less energy needs to be transferred to the ink for it to vaporise.

Furthermore, as the asymptotic value of volume VOL of the ejected droplet does not remain constant but instead increases with the rise in temperature Ts of the substrate, mainly due variations in viscosity of the ink; this phenomenon is related to the chemical and physical characteristics of the ink and can be minimised to at least within a certain temperature range, by appropriately defining the ink's composition.

Finally, accompanying the change in temperature Ts of the substrate, there is also a change in the value of Eg: Fig. 3 illustrates graphically by means of the dashed line 1 the experimental pattern of knee energy Eg in function of temperature variations (delta T). The reference unit of measure taken for the energy is the value of Eg at starting temperature (delta T = 0 °C), at a temperature of 20 °C for example, which is the generally accepted ambient temperature.

In Fig. 3, dashed line 5 represents the constant value of El, selected for example at 1.05 on the basis of the remarks made above; from Fig. 3, it will be seen immediately that for delta T = 0 °C, the difference between working energy El and knee energy Eg is 0.05, whereas for delta T = 20 °C for example, the difference, represented by the segment included between points A and B, is 0.11, i.e. more than double the previous value.

This is indicative of the risk, if no remedial action is taken, of a phenomenon of degeneration setting in whereby the more the temperature of the substrate increases, the greater the portion of energy supplied to the resistor, resulting in a further increase in temperature of the substrate.

To solve this problem, methods and devices have been suggested in the known art with the principal aim of controlling temperature Ts of the substrate, in other words of having the head work at an essentially constant substrate temperature Ts, so that the Eg value remains constant

For example, systems have been suggested for maintaining temperature Ts of the substrate constant by slowing down the printing speed (and thus reducing the frequency at which droplets are ejected) to increase the time available for the head to cool naturally and settle at an acceptable temperature value, or also by stopping printing when temperature of the substrate exceeds a predetermined level. This however is detrimental to the work performance speed (or "throughput"), a requirement rated ever more highly by the users of ink jet printers.

Further, systems have been suggested for maintaining the temperature Ts of the substrate constant by using, for example, supplementary resistors in addition to the ejection resistors, to heat the head as necessary so that it works permanently at a predetermined maximum temperature. This makes construction and opera-

tion of th head more complex, additionally requiring a temperature sensor and an additional circuit for supplying energy to the supplementary resistors.

Still further, systems have been suggested for maintaining the temperature Ts of the substrate constant by using, for example, the same ejection resistors to heat the head and have it work permanently at a predetermined maximum temperature. In this case, the ejection resistors of those nozzles that are not required to eject ink drops are still heated, but with energy pulses with a frequency that is too high to produce ejection of a droplet; however, this solution also requires a temperature sensor and an additional circuit for supplying the heating pulses with characteristics different from those required for ejection of the droplets.

All the suggested solutions known in the art, as seen above, have drawbacks, so that the problem of simply, effectively and inexpensively stabilizing the energetic operating point of the ejection resistors of an ink jet printhead has still not been resolved satisfactorily.

Summary of the invention - It is a principal object of the present invention to define an ink jet printhead with integrated drive components, characterized by the fact that it comprises compensation means for automatically compensating the energetic operating point of the ejection resistors on variations of temperature.

It is another object of the present invention to define an ink jet printhead comprising a semiconductor substrate on which are integrated ejection resistors and MOS transistors for supplying energy to the resistors, characterized by the fact that automatic compensation of the energetic operating point of the ejection resistors on variations of temperature of the substrate is provided using the channel resistance of the conducting MOS transistors.

It is a further object of the present invention to define an ink jet printhead comprising a semiconductor substrate on which are integrated ejection resistors and MOS transistors for supplying energy to the resistors characterized by the fact that the Rc/R ratio of the conduction channel resistance Rc of the MOS transistors to the resistance R of the ejection resistors has an established value of between 0.10 and 0.25.

It is another object of the present invention to define a method of printing with an ink jet printhead comprising resistors for ejection of the ink droplets and MOS transistors for supplying energy to said resistors, all integrated on a common semiconductor substrate, characterized by the fact that the printhead has compensation means for automatically compensating the energetic operating point of the resistors on variations of temperature of the common substrate, means comprising the channel resistance during conduction of the MOS transistors.

It is a yet further object of the present invention to define a method of automatically compensating the energetic operating point of the ejection resistors of an ink jet printhead, on variations of t mperature of the substrate comprising the integrated ejection resistors.

The above objects ar achieved by means of a method for automatically compensating the energetic operating point of the ejection resistors of an ink jet printhead and associated printhead, characterized according to the main claims.

These and other objects, features and advantages of the present invention will become more apparent upon consideration of the following description of a preferred embodiment, provided by way of a non-exhaustive example, in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1.- Represents a circuit diagram of an integrated printhead, comprising ejection resistors and MOS drive transistors connected in a matrix.

Fig. 2.- Represents a graph of the pattern of droplet volume in function of the energy supplied to the ejection resistor.

Fig. 3.- Represents a graph of the pattern of knee energy Eg in function of temperature, and of working energy El for different values of the Rc/R ratio, also in function of temperature.

Fig. 4.- Represents the equivalent electric diagram of the conducting MOS transistor that drives resistor Ri.

Fig. 5.- Represents a graph of the pattern of the channel resistance value Rc during conduction, in function of substrate temperature Ts.

DESCRIPTION OF THE PREFERRED EMBODIMENT

With reference to Fig. 1, if the resistance of transistor Ti during conduction is ignored for the sake of simplicity (this resistance can be rendered extremely small by suitably determining size of transistor Ti), when electronic controller 101 drives (i.e. supplies energy to) ejection resistor Ri by causing the MOS transistor TRi connected to it to conduct, the equivalent electric circuit is as shown in Fig. 4.

If R is taken to indicate the resistance of ejection resistor Ri, Rc represents the channel resistance of MOS transistor TRi during conduction, V is the voltage powering the circuit illustrated in Fig. 1, and t is the time during which MOS transistor TRi is maintained in conduction by electronic controller 101 in order to produce ejection of a droplet of ink by ejection resistor Ri, the total energy Et supplied by the voltage V power supply is expressed by the following equation:

$$Et = V^2 t/(R + Rc). \qquad (2)$$

This energy is shared between the ejection resistor and the MOS transistor, since R and Rc form a resistive divider, and thus only th portion

$$El = V^2 Rt/(R + Rc)^2 \qquad (3)$$

dissipated on the ejection resistor effectively contributes to ejection of the droplet, whereas the remaining portion is dissipated thermically on the channel resistance Rc. From this viewpoint, the known art counsels designing the MOS transistor TRi with a channel resistance Rc as low as possible (ideally 0): the merit of the present invention is that of having identified a way of taking advantage of the existence of a channel resistance Rc other than 0 in order to obtain automatic compensation of the energetic operating point of each ejection resistor Ri on variations of the substrate temperature.

It is known, in fact, that the channel resistance Rc of a conducting MOS transistor between drain and source (i.e. between the electrodes that in a bipolar transistor are known respectively as collector and emitter) varies in function of temperature according to a characteristic represented in Fig. 5 by the dashed line 4, showing how Rc varies in linear fashion in function of temperature Ts.

The characteristic variation of channel resistance Rc with temperature is typically in the region of +1%/°C, i.e. it may be represented by the following equation:

$$Rc_{T1} = Rc_{T0}\,[1 + 0.001\,(T1 - T0)]. \qquad (4)$$

Also known is that the characteristic variation of thermal energy Eg with temperature is typically in the region of -0.3%/°C; this in turn may be represented by the following equation:

$$Eg_{T1} = Eg_{T0}\,[1 - 0.003\,(T1 - T0)]. \qquad (5)$$

As Rc belongs to the denominator of equation (3), an increase in its value as temperature rises results in a corresponding decrease in the value of El, and it is thus possible to determine a field of values for resistance Rc such that, at least within a defined range of temperatures, the decrease in the value of El optimally compensates the parallel decrease in the value of Eg. The overall result obtained is that the value of El automatically adapts to variations of the value of Eg as temperature Ts of the substrate varies, thereby maintaining the El - Eg difference constant.

Still in Fig 3, the bunch of straight lines 2 represents the pattern of energy El, normalized to a starting temperature value equivalent to 1.05 times the initial value of Eg, for different values of the Rc/R ratio at starting temperature (from Rc/R=0.05 to Rc/R=0.35) of channel resistance Rc of the conducting MOS transistor, to resistance R of the ejection resistor connected to it. As may be seen in Fig. 3, when the value of this ratio is between approximately 0.10 and 0.25, preferably between 0.15 and 0.21, the pattern of straight lines representing the knee energy Eg and working energy El is substantially parallel, meaning that their respective values decrease by like amounts and that accordingly the difference between them remains constant on variation of the substrate temp rature Ts.

All other values of the ratio Rc/R outside the range indicated above result in an imbalance above or below the optimum El - Eg difference value, with the resulting drawbacks described in the foregoing.

It will therefore be clear that, by exploiting the known semiconductor technology techniques to design the ejection resistors Ri and relative MOS drive transistors TRi so that the ratio Rc/R at a standard ref rence temperature (for example 20 °C) is between 0.10 and 0.25, the result may be obtained of keeping the El-Eg difference constant over a broad substrate temperature Ts variation range, and thus also of automatically compensating the energetic operating point of the ejection resistors.

Those skilled in this field will also appreciate the fact that the ink jet printhead and method of operation described above mean that the MOS transistors for driving of the ejection resistors may be built smaller in size than would be necessary to obtain the very low channel resistance values Rc, that are considered preferable in the known art, if only for the fact that they minimize the amount of energy dissipated by the MOS transistor TRi when conducting.

Further, as the geometric structure of the printhead circuit generally requires the ejection resistors to be very close physically to the associated MOS drive transistor, the compensation between energy El and energy Eg is performed in an extremely localized manner, nozzle by nozzle, and is therefore extremely effective even in cases where significant differences in temperature arise between the areas of the head as a result of the printing method not involving all the nozzles in a uniform way.

Those skilled in the art of this sector may easily identify variants or changes to the ink jet printhead and method of operation described above, without exiting from the scope of this invention.

For example, a printhead with a different scale of component integration may be used, one for example comprising not only the MOS drive transistors, but also logic type circuits (shift registers, decoders, etc.).

Furthermore, the printhead may be of the removable type, fitted on a carriage that runs across the entire width of the sheet of paper that is being printed on, or of the fixed type capable of ejecting droplets of ink along the entire width of the sheet (line head).

It is also possible, for example, to use printheads for black and colour printing, in which the ink reservoirs, instead of being integrated in the head (the type of printhead known as "monobloc"), are removable and replaceable so that once they are empty, only the reservoir and not the entire printhead need be replaced ("refillable" heads).

In short, while adhering to the principle of this invention, details of the design and the forms of embodiment described and illustrated in the foregoing may be amply modified, without exiting from the scope of the invention.

Claims

1. An ink-jet print head (100) comprising at least one resistor (Ri) for ejecting droplets of ink, and at least on MOS transistor (Tri) for supplying energy to said at least one resistor, said at least one resistor and said at least one MOS transistor being both integrated on a common semiconductor substrate, characterised in that it further comprises compensation means for automatically compensating the energetic operating point (EI) of said at least one resistor with respect to changes in temperature (Ts) of said common substrate.

2. An ink-jet print head according to claim 1, in which said at least one MOS transistor (Tri) has a channel resistance (Rc), characterised in that said compensation means comprise said channel resistance during conduction of said at least one MOS transistor.

3. An ink-jet print head according to claim 2, in which said at least one resistor (Ri) has a resistance value R and said channel resistance during conduction has a value Rc, characterised in that the ratio Rc/R has a determined value of between 0.10 and 0.25.

4. An ink-jet print head comprising at least one resistor (Ri) for ejecting droplets of ink having a resistance value R, and at least one MOS transistor (TRi) for supplying energy to said resistor having a channel resistance during conduction of value Rc, characterised in that the ratio Rc/R has a determined value of between 0.10 and 0.25.

5. An ink-jet print head according to claim 4, characterised in that said at least one resistor (Ri) and said at least one MOS transistor (Tri) are both integrated on a common semiconductor substrate.

6. An ink-jet print head, comprising at least one MOS transistor (Tri) for supplying a working energy EI greater than a knee energy Eg and at least one resistor (Ri) for ejecting droplets of ink, said at least one MOS transistor and said at least one resistor being both integrated on a same semiconductor substrate, characterised in that said working energy EI is greater than said knee energy Eg by a given amount, said amount remaining constant on variations in temperature (Ts) of said substrate.

7. An ink-jet print head according to claim 6, in which said at least one MOS transistor (Tri) has a channel resistance during conduction Rc and said at least one resistor (Ri) has a resistance R, characterised in that the ratio Rc/R has a determined value of between 0.10 and 0.25.

8. A method for printing with an ink-jet print head, characterised in that it comprises the following steps:

   - having a print head comprising at least one resistor (Ri) for ejecting droplets of ink, and at least one MOS transistor (Tri) for supplying energy to said at least one resistor, said at least one resistor and said at least one MOS transistor being both integrated on a common semiconductor substrate, and said at least one MOS transistor having a channel resistance (Rc);
   - having compensation means for automatically compensating the energetic operating point (EI) of said resistor with respect to temperature variations of said common substrate, said compensation means comprising said channel resistance (Rc) of said MOS transistor during conduction.

9. A method for compensating the energetic operating point (EI) of an ejection resistor (Ri) having a resistance of value R, integrated on a semiconductor substrate of an ink-jet print head(100), characterised in that it comprises the following steps:

   - integrating on said substrate a MOS transistor (Tri) for supplying energy to said resistor,
   - defining a channel resistance during conduction Rc of said MOS transistor such that the ratio Rc/R has a determined value of between 0.10 and 0.25.

10. An ink-jet printer having a print head (100) mounted on a carriage capable of performing a forward motion and a backward motion all along a width of a printing medium for depositing droplets of ink on said printing medium, characterised in that said print head is according to any one of the claims from 1 to 7.

11. An ink-jet printer according to claim 10, characterised in that said print head (100) is of the type with replaceable ink reservoir.

12. An ink-jet printer having a fixed print head (100) for depositing droplets of ink on a printing medium, characterised in that said print head is according to any one of the claims from 1 to 7.

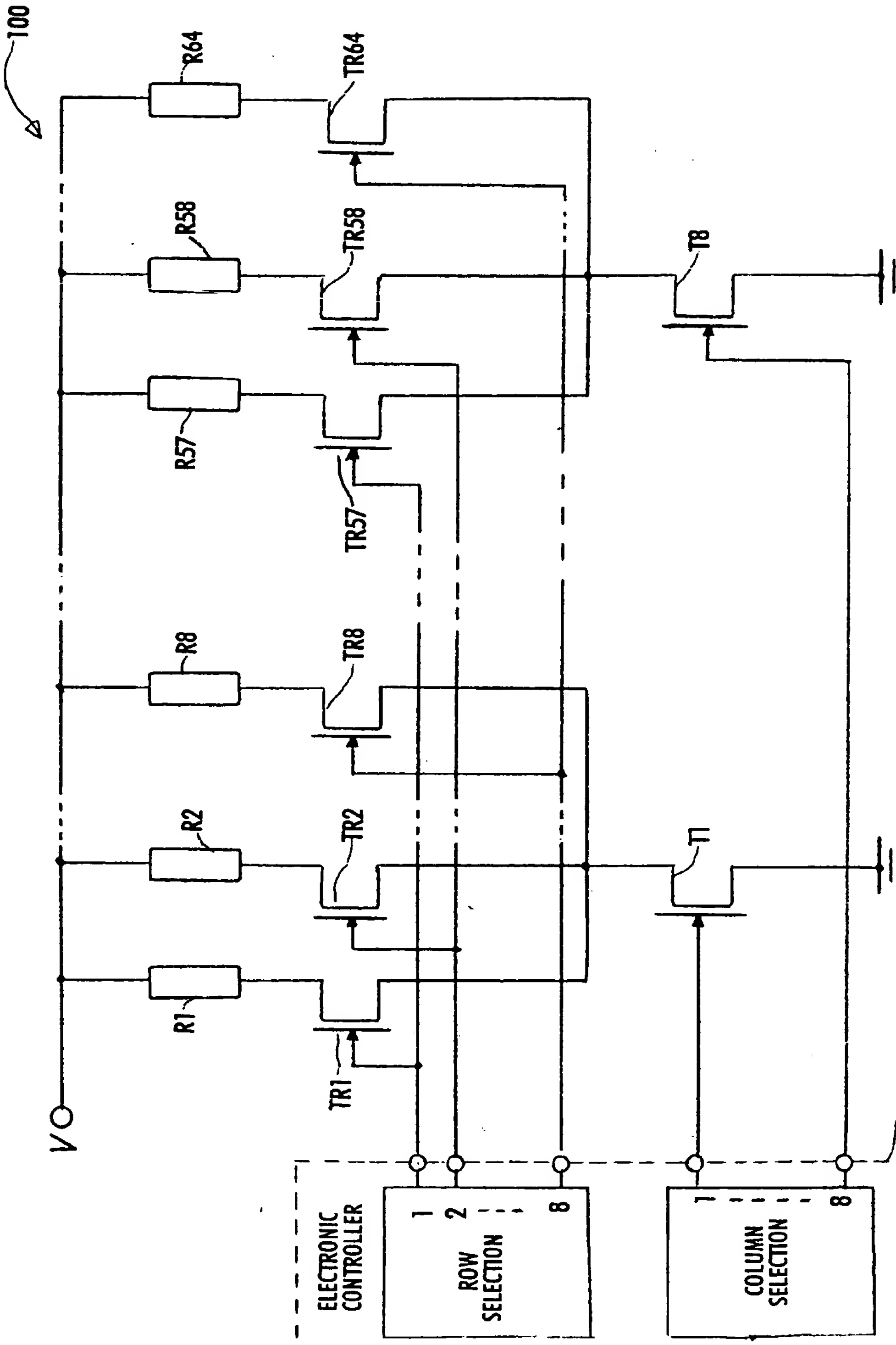
100
R64
TR64
R58
TR58
T8
R57
TR57
R8
TR8
R2
TR2
T1
R1
TR1
V
101
ELECTRONIC CONTROLLER
ROW SELECTION
1
2
8
COLUMN SELECTION
1
8

FIG. 1

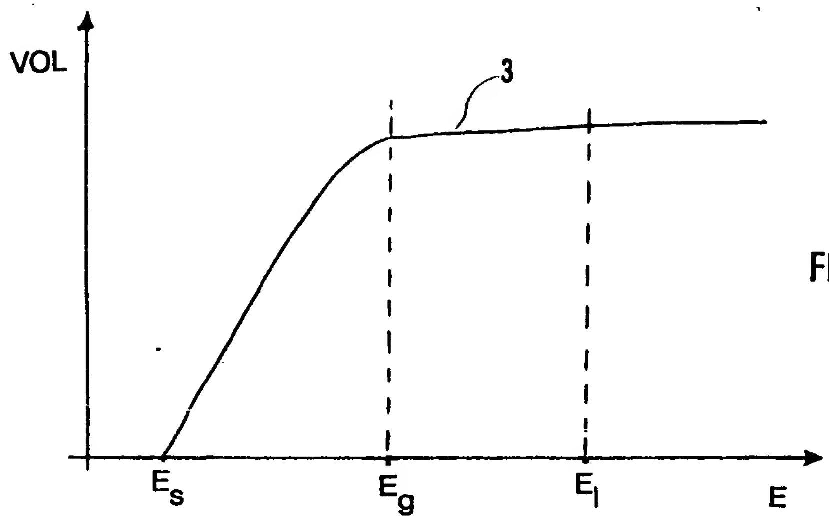

FIG. 2

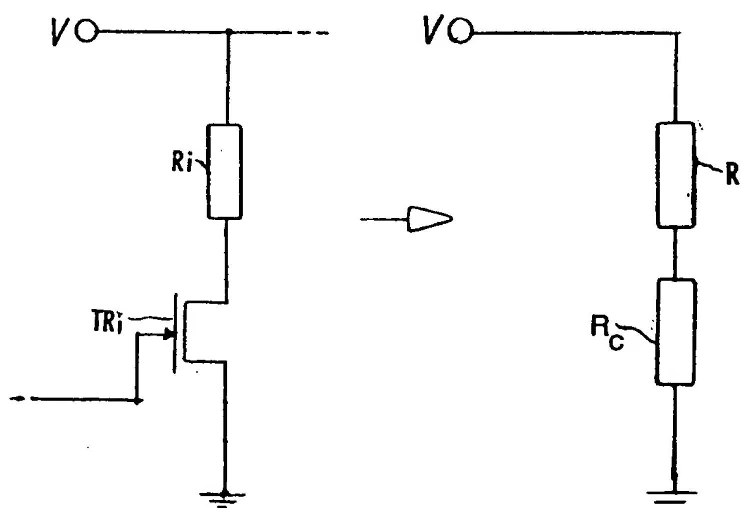

FIG. 4

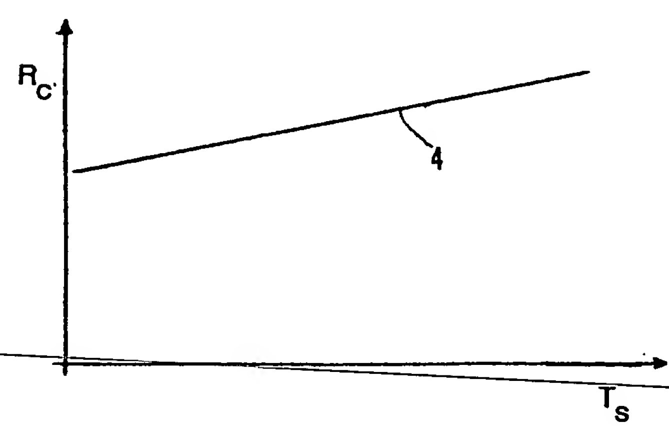

FIG. 5

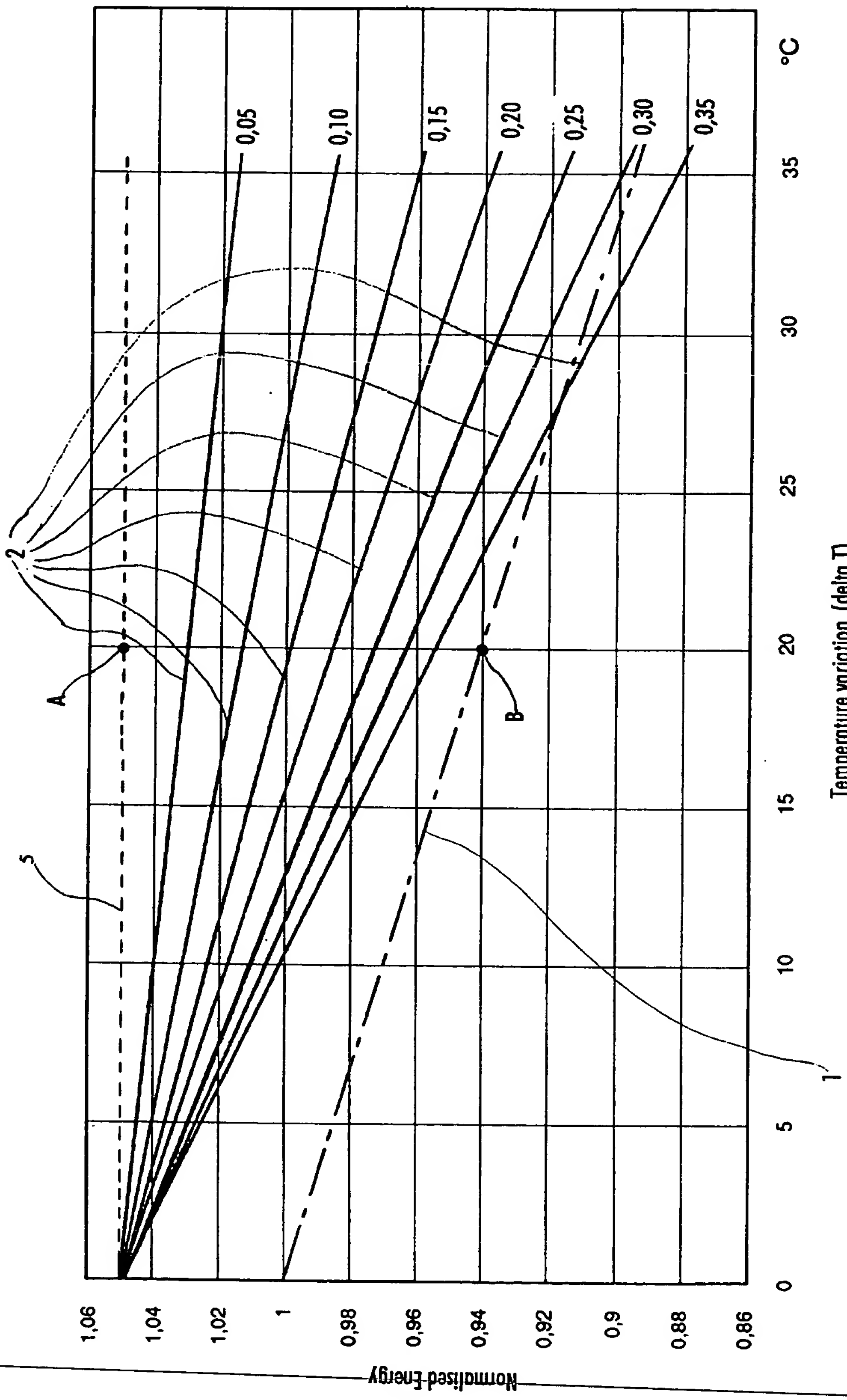
Normalised Energy
1,06
1,04
1,02
1
0,98
0,96
0,94
0,92
0,9
0,88
0,86
Temperature variation (delta T)
0
5
10
15
20
25
30
35
°C
0,05
0,10
0,15
0,20
0,25
0,30
0,35
A
B
1
2
5

FIG. 3